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Oceangoing Marine Vessel Emission Control Technology Matrix - October 30, 2002

Control Technology	Manufacturers	New/Retrofit/Both	Current Installations	Time to Install	Percent Reductions		Estimated Cost Parameters		Pros	Cons	Comments/References/Notes
			2-Stroke/4-Stroke/Both		NOx	PM	Eqpmt. & Install.	Operation & Maint.			
Continuous Water Injection (aka Water in Fuel Injection)	MAN B&W										
	M.A. Turbine/Engine Design	Both	Both	~10 working days	up to 30%	up to 25%	~$33K	~$530/year	Reduced fuel consumption; can be operated without engine modifications; compact size		Optimum water/fuel ration is ~10% (fuel penalties start occurring above 25%); <u>Cost/Benefit Study of Marine Engine NOx Emission Control Systems</u>, Transport Canada, 2/2000; no current applications known, but was previously applied to a B.C. Ferries vessel
	Wärtsilä-Sulzer	Both (Note: only support to customer for system specification, but no specific systems/manufacturer and no sales activity); developmental	Unknown; developmental	Rough estimations: Approx. 2 weeks for emulsion system only; additional time (1-2 weeks) for adapting fresh water generator; Note in case of retrofits: except time for installation additional time for certification by classif. societies may be necessary (any change of components, additional tubes, pumps has to be reported to the class)	20-30%	no specific data; literature expects no negative influence regarding the carbon fraction of PM (as OH-radicals might oxidize carbon)	2 stroke: estimated costs $13/kW (for emulsifying system only); plant for increased water production not included (depends on specific vessel type/application)	?		Emulsion stability; fuel injection system capacity; poor performance when not using emulsion; injection system cavitation risk	
Direct Water Injection	MAN B&W										
	Wärtsilä-Sulzer	2-strokes: both in 5 years; 4-strokes medium speed only now both new and retro	4-stroke (~50 engines installed or on order)	Rough estimations: Approx. 3 weeks for DWI system only(depending on cyl.number); additional time (1-2 weeks) for adapting fresh water generator; Note in case of retrofits: except time for installation additional time for certification by classif. societies may be necessary (any change of components, additional tubes, pumps has to be reported to the class)	50-60%	no data yet	$15-$30/kW new	$1-$3 USD/MWh	Significant NOx reductions; consume only water; water-efficient	Methods using water for NOx reduction require high amounts of fresh water (60-70% of fuel amount estimated), which might not be available at low loads (produced by fresh water generators) or in coastal regions, where the sea water quality might not be good enough for fresh water generators; may cause corrosion in cooler running 2-speeds	Field tests planned 2003/2004 in order to investigate long term behaviour; serial version available 2006. Works same regardless of S content of fuel. But high-S fuels there is indication of corrosion, but not if operating on low S fuels. If 2-strokes operated longer times with low S fuels the cylinder lubrication may need to be adjusted (increased lubrication).

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Humid Air Motor	M.A. Turbine/Engine Design										
	Seaworthy Systems										
	SEMT Pielstick		4-Stroke		70-80% (depending on load conditions)				No increase in smoke or HC emissions; humidification tower can replace the engine intercooler		Offered as an option available for a number of 4-stroke Pielstick engines
	Wärtsilä-Sulzer: not promoting this technology. Prefer CASS - see below.									Humidification of the scavenge air might not be suitable on 2-stroke engines (not tested yet), due to concerns regarding the scavenging process with humid air over the whole stroke of the cylinder liner and affecting the oil film.	
Combustion Air Saturation Systems (CASS)	Wärtsilä-Sulzer	Avail in 5 years for both new and retro 4-stroke (not available on 2-stroke engines!)			70%					High amounts of water needed; Humidification of the scavenge air might not be suitable on 2-stroke engines (not tested yet), due to concerns regarding the scavenging process with humid air over the whole stroke of the cylinder liner and affecting the oil film.	
Emulsified Fuels	Lubrizol (PuriNOx); Elf Aquitaine (Aquazole); A-55, Inc., Petroleos de Venezuela SA (PDVSA); BIMIX Korea (RE-30 and RE-50); Komatsu (engine & emulsion equip); MAN B&W, Reson, Pielstick (FWE equip)	Both	Both	None for emulsions; unknown but probably minimal for FWE equipment	15-50% (emulsions vs. on-board FWE systems)	50-63%	\$0 - \$217K	\$0 - \$36K	Engine modifications not always necessary, except for on-board fuel-water emulsion systems; cost of emulsions should be similar to diesel; RE-30 claims higher fuel efficiency	Possible increase in HC and CO2; limited shelf life for emulsified fuels; slightly reduced power output; fuel penalty up to 1.5%; not applicable for all engines due to power reduction	City of Houston Diesel Field Demonstration Project, Environment Canada; Cost/Benefit Study of Marine Engine NOx Emission Control Systems, Transport Canada (February 2000); New Technologies and Alternate Fuels, John J. McMullen Associates, Inc. (January 2002); http://www.bimixkorea.co.kr/eng/main.htm
Cleaner Fuel - 1.5% sulfur HFO	N/A (numerous)	Both	Both	Unknown for tanks & piping.	0	18% (and SOx 44%) USEPA	\$50,000/cat 3 engine (USEPA)	Fuel 60% higher (USEPA)	Significant PM/SOX reds; lower initial investment	High Cost of fuel, negligible NOx benefit	Already implemented in the Baltic region via IMO. Analysis of 1.5% sulfur fuel option in USEPA Cat 3 staff report.
Cleaner Fuel - Biodiesel	Numerous suppliers; a list of US suppliers available at www.biodiesel.org	Both	Both; harbor vessels only to date	None	1% to 18% increase	18% to 35% decrease (note: this based on testing of medium and high speed engines)	None	15¢ to \$1.60 per gallon above on-road diesel (depends on blend and wholesale vs. retail)	No installation costs; can be blended with diesel distallate; no engine modifications needed if used as in 80%/20% diesel/biodiesel blend; produced from renewable resources and/or waste fats; adds lubricity in low-sulphur fuels.	Limited availability; increased operating costs; increased NOx	

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Cleaner Fuel - CARB On-Road Diesel	N/A (numerous)	Both	Both	Unknown for tanks & piping/ 20-60 min to switch fuels	~16%	~72% (and 99% SOx)	$50,000/cat 3 engine (USEPA)	Fuel 2.5x cost of residual (USEPA)	Very significant PM/SOx reductions; low initial investment.	Very high cost of fuel; 20-60 min. to switch to distillate.	Could be implemented only in target areas to minimize cost impact
Cleaner Fuel - IFO 180	N/A (numerous)	Both	Both	Unknown	Small; unknown	Unknown	$50,000/cat 3 engine (USEPA)	Fuel ~5% higher (www2.mgn.com)	Low initial investment; similar to existing residual fuel	Negligible NOx benefit, and unkown probably modest PM benefit	Reportedly utilized by cruise ships to meet Alaskan opacity limits
Cleaner Fuel -MGO	N/A (numerous)	Both	Both	unknown for tanks & piping/ 20-60 min to switch fuels	10%	63% (and 89% SOx) USEPA	50,000/cat 3 engine (USEPA)	fuel ~2x cost of residual	Low initial investment; significant PM/SOx reductions	Very high fuel cost; 20-60 min. to switch to distillate	Similar to CARB diesel option; could be implemented only in target areas; analysis of MGO in USEPA Cat 3 staff report
Fuel Injection Modifications	Wärtsilä Mini-Sac Fuel Injectors	Both ?	Both?	Unknown		50%	See comments		Also reduces THC by 70%		Installed on new engines, can't separate costs for different fuel injection system; improves fuel economy at low-mid speed which helps to offset costs
	Sulzer's RT-Flex Engine w/Wärtsilä's WECS-9500 Electronic control	New	2-stroke	Unknown	20%		See comments		No visible smoke at any speed; steady operation at very low running speeds		Also controls exhaust valve actuation, allows for variable exhaust valve timing; NOx can be selectively reduced by 20% while in certain areas; installed on new engines, can't separate costs for different fuel injection system; improves fuel economy at low-mid speed which helps to offset costs
	Wärtsilä Common Rail for four stroke engines	New	4-stroke	Unknown			See comments		Steady operation at very low running speeds		Installed on new engines, can't separate costs for different fuel injection system; improves fuel economy at low-mid speed which helps to offset costs
	MAN B&W? Slide-type fuel valve	Both ?	2-stroke	Unk	10-25%	50%	See comments		Slide-type fuel valve reduces THC and soot emissions by decreasing fuel seepage		Installed on new engines, can't separate costs for different fuel injection system; improves fuel economy at low-mid speed which helps to offset costs
	Wärtsilä-Sulzer Low-NOx Injection Technology: high compression ratio, retarded injection timing, late exhaust valve closure, optimized fuel injection (nozzle specification)	Both (Note: retrofits need a lot of time and money, depending on engine type and cyl.number)	All new engines, which have been installed on vessels with keellaying on or after 01.01.00 (Annex VI)		5-10% beyond Annex VI NOx limits		New injection nozzle tips (costs depending on cyl.number), in few cases (depending on engine type) also new actuator cams, pistons, cyl.covers; reconditioning cylinder liners			Fuel penalty	Retrofits are quite time consuming, due to reconditioning of cylinder liner, readjustment of fuel pumps, cams, engine control system and installation of new components
	High Pressure Fuel Injectors (CBOI)	Both	Both		25-30%	25-30%	Available		Will work on large ships and various fuels; improves fuel economy		Improves fuel atomization - decreases NOX and PM and improves fuel economy.

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Exhaust Gas Recirculation	Contractors	Retrofit	Both	2-3 days	15-20%	Slight increase			Not expensive; easy to install	Need to remove PM	PM must be removed/reduced before EGR. Works with regular marine diesel, but bunker fuel has very high sulfur and this may not work
Injection Timing Retard		Both ?	Both?	Unk	Decrease	Increase?	See comments		Reduces NOx emissions	Increase fuel consumption and PM; decrease power	
Electronic Engine Management Systems		Both	Both		25-30%	25-30%	Available		Will work on large ships and various fuels; improves fuel economy		This technology electronically controls air-fuel ratios.
Cooling Air Charge		Both	Both				Available		Will work on large ships and various fuels; improves fuel economy		Lean burn process; lowers combustion temperature; lowers Nox and PM; increases fuel economy.
Selective Catalytic Reduction	Ceramics GmbH & Co. KG (SINOx SCR System); Wärtsilä-Sulzer; MAN B&W; RJM Corporation; and others	Both; retrofit-solutions for 2-stroke engines are more difficult than for 4-stroke engines because of the required minimum temperature for the SCR system to perform	Both	Depends on the number of SCR systems installed - is normally done during a planned overhaul / repair of the vessel	Typical NOx reductions for vessels are between 80% and 90%; SCR capability is >90%; no NOx reductions at <25% load		Total costs $260K to $1.23M ($30-$70 per kW, depending on the number of SCR systems installed and the required NOx reduction)	$1.30/gal for aqueous urea (total costs/US flag depending on engine size $24K-$144K); may need routine cleaning; replacing reactor elements 5-15 yrs depending on the fuel used;	High NOx reductions; possibly lower fuel consumption	Requires a significant amount of space; uses 0.5%-1% sulfur or distillate fuel; sulfur in fuel is a concern for compact SCR; additional tank to store ammonia or urea; reactors need constant cleaning using either ultrasound or compressed air; high costs	SCR system can be designed to fit into tight spaces which might restrict the reduction rate; to address the space issue, one manufacturer is developing a compact system which uses an oxidation catalyst upstream of the reactor; see EPA Draft Regulatory Support Document for C3 Marine Engines, 4/02
Diesel Oxidation Catalyst	Clean Air Systems, Donaldson, Engelhard, Johnson-Matthey, Nett Technologies, Inc.	Both	Have not located any marine installations	Estimate 4 to 12 hours	No Impact	15 to 30% (reduces the SOF portion of the PM)	$150-$500 installation, $3-$15 per horsepower		Less expensive than DPF techology; reduces SOF (formaldehydes, acetaldehydes, acrolien, 1,3 butadiene, PAH); up to 90% effective for HC and CO emissions; no fuel economy impact	Sulfur content in the fuel has a strong impact on PM reductions; high sulfur fuels used with DOC can produce increased PM emissions due to sulfate formation (SO3 +H2O)	Cost Information from stationary engine estimates and from MECA found at www.nan.usace.army.mil/front/aqfinal.pdf; manufaturers from stationary engine list; technical info from www.osti.gov/hvt/deer2000/whitacpa.pdf; most of the info based on mobile or stationary applications
Fuel Cells	Marine Fuel Cells, Inc. - AQMD received PON response; Need to check Navy projects	New			App. 100%	App. 100%	$3000-$5000/kW		Near-zero emissions	Expensive; reform base fuel to hydrogen	This proposal is for a barge that will provide hotelling electrical power to ships. Fuel cells will also provide barge propulsion power. Fuel cells are PEM type.
Non-thermal Plasma	Litex, Delphi, ECOZONE, PlasmaSol, AEA Technology, HI-Z Technology	Both	Unknown	Unknown	Up to 90%	~30%	Unknown; still developmental	Unknown; still developmental	Simple concept; excellent NOx reduction potential	Still developmental; requires electrical power to be supplied to the unit	http://www.trucks.doe.gov/research/engine/ntp-catalyst.html; DieselNet; WTA report
NOx Adsorber	Engelhard, Cummins, Johnson-Matthey	Not available at this time (proprietary)	Not available at this time (proprietary)	Not available at this time (proprietary)	Not available at this time (proprietary)	N/A	Not available at this time (proprietary), but staff was told it will be quite expensive	Not available at this time (proprietary)	An additional option in the effort to reduce emissions of criteria pollutants from marine vessels	Cost; not commercially available at this time, and information needed to properly evaluate the technology considered proprietary by technology developers	

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Diesel Particulate Filter	Airmeex, Catalytic Exh. Prod, Oberland Mangold, Paas Technologies, Inc., 3M Corp., AirCor Corp., Buck TSP, Cha Corporation, Clean Air Systems, Corning, Inc., DCL International, Inc., Donaldson Company, Inc., Doubletree Technologies, Engelhard Corp., Engine Control Systems, Johnson-Matthey, Miratech Corporation, Nett Technologies, Inc., Rypos-Bekaert	Both	Typically 4 stroke; unknown effectiveness on 2-stroke engines	Estimate 4 to 12 hours	Typically no impact on NOx; may impact the NO/NO2 ratio of total NOx	70 to 90%	$14 to $30 per hp	$150 to $300 per year	High PM reductions, may provide passive, or active (automated) regeneration	Sulfur content in the fuel may impact the effectiveness of some passive (catalyzed) filters; passive regeneration dependent on exhaust temp duty cycle; high costs for retrofit; may have fuel penalty for certain types of actively regenerating systems (fuel burners, electric regeneration)	www.marad.dot.gov/NMREC/conferences%20&%20workshops/jan%2029-30%202002/dehart.pdf; Navy Pilot Retrofit Program includes Rypos Filter; cost estimates from MECA found at www.nan.usace.army.mil/front/aqfinal.pdf